COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

TITLE: Minutes of the Explosives Safety Seminar (22nd) Held in Anaheim, California on 26-28 August 1986. Volume 1.

TO ORDER THE COMPLETE COMPILATION REPORT, USE AD-A181 274.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDING, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

AD#: P005 302 thru P005 349	AD#:
AD#:	AD#:
AD#:	AD#:

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

AD-P005 344

DEBRIS HAZARD AT A ROCKET MOTOR TEST CELL FACILITY-- AN "ACCIDENTAL" STUDY

by

Patricia Moseley Bowles
and
Michael A. Polcyn

Southwest Research Institute
San Antonio, Texas

ABSTRACT

The J-5 test cell at Arnold Engineering Development Center (AEDC) is the only national facility for testing large solid-propellant rocket motors at simulated flight-altitude conditions. However, the cell was not sited to meet the quantity-distance criteria required for testing motors containing propellant equivalent to 20,000 lb of TNT. This motor and other motors containing similar propellant amounts were being tested in J-5 using explosives safety waivers since no other facility is available in which to test them. Safety personnel concerned with the serious potential hazards for other unique test capabilities at AEDC funded a study to examine the distribution of debris and define the hazard at the J-5 test cell resulting from accidental detonation of rocket motors containing propellant equivalent to 20,000 and 30,000 lb of TNT. While the study was in progress, an actual mishap occurred during a test of one of the motors being examined in the study. The estimated sequence of events during the mishap and the distribution of motor, test cell, and building debris after the accident as compared with predicted debris arcs are presented in this paper.

1.0 INTRODUCTION

Southwest Research Institute (SwRI), as a subcontractor to Lawrence Livermore National Laboratory (LLNL), has been consulting Arnold Engineering Development Center (AEDC) on potential debris distribution problems at the J-5 and proposed J-6 rocket test facilities. The J-5 test facility at AEDC, shown in Figure 1, is the only large national facility for testing solid propellant rocket motors at simulated flight-altitude conditions. However, some motors currently in need of altitude testing and future motors to be tested exceed the test capability of J-5 in nominal thrust and in the amount of propellant contained in the motors. Some of these motors were being tested in J-5 with explosives safety waivers since the location of the facility does not meet quantity-distance criteria required by safety regulations for the type and amount of propellant involved. Safety personnel became concerned with the potential debris hazard which may result from testing motors under safety waivers.

In November 1985, SwRI was analyzing the distribution of debris which would result from an accidental detonation of propellant equivalent to 20,000 and 30,000 lb of TNT in the J-5 test cell. On November 23, 1985, during a qualification test of a rocket motor, a mishap occurred. At the request of LLNL and with permission from AEDC, an SwRI team was sent to investigate the mishap site with special emphasis on collecting data on the distribution, size and nature of the resultant debris created by the event. This paper summarizes SwRI's investigation and post-mishap analysis results. Debris hazard zones predicted for an accident at J-5 are compared to the actual distribution of motor, test cell, and building debris after the mishap.

2.0 ANALYTICAL DEBRIS DISTRIBUTION STUDY

The emphasis of the original analytical study of the rocket motor detonation was the distribution of debris from the J-5 enclosure building, tne test cell and the motor being tested. A previous study (Reference 1) conducted by SwRI to analytically determine the debris distribution around an accidental motor detonation indicated directional debris throw and the existence of some

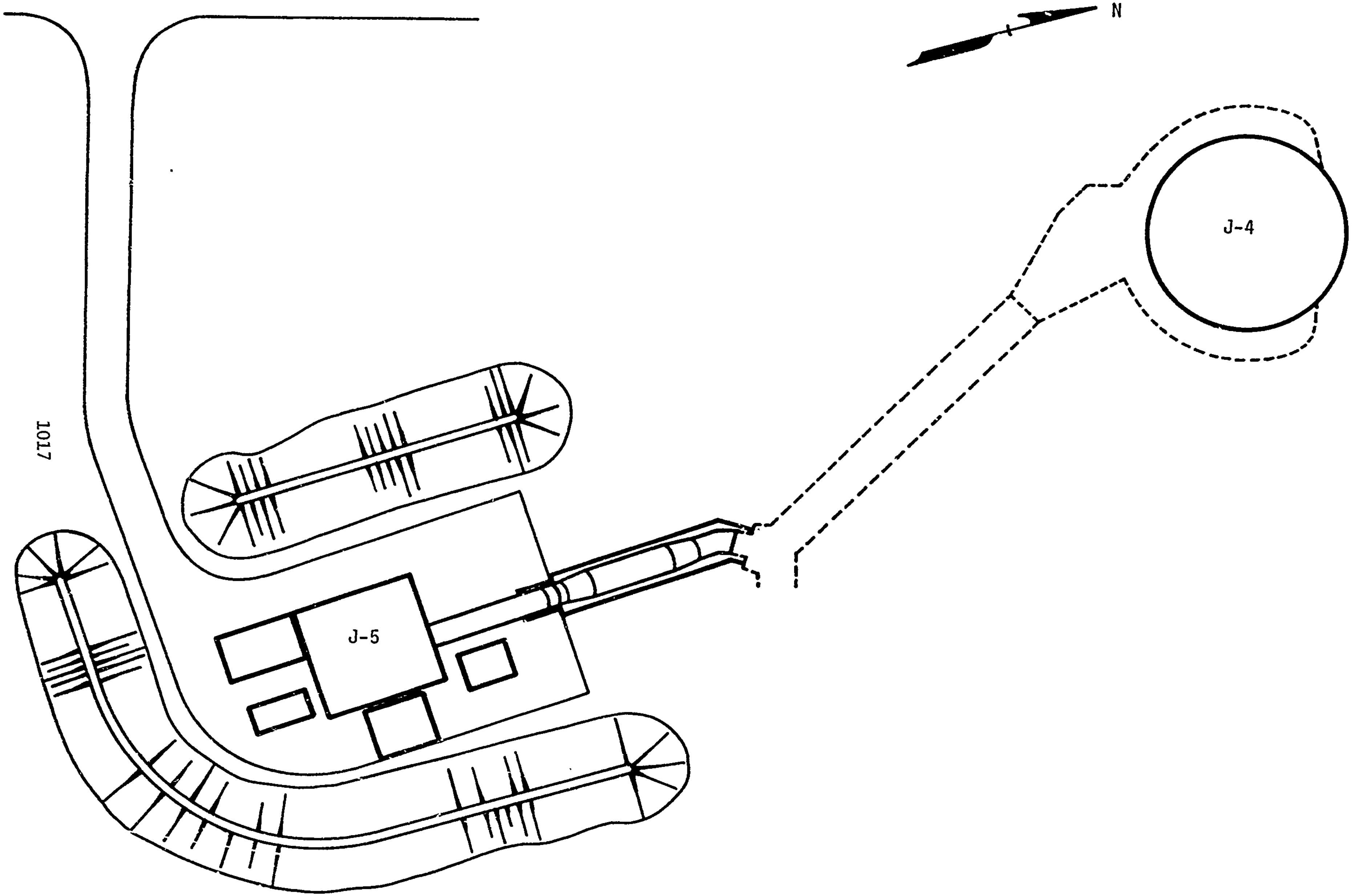
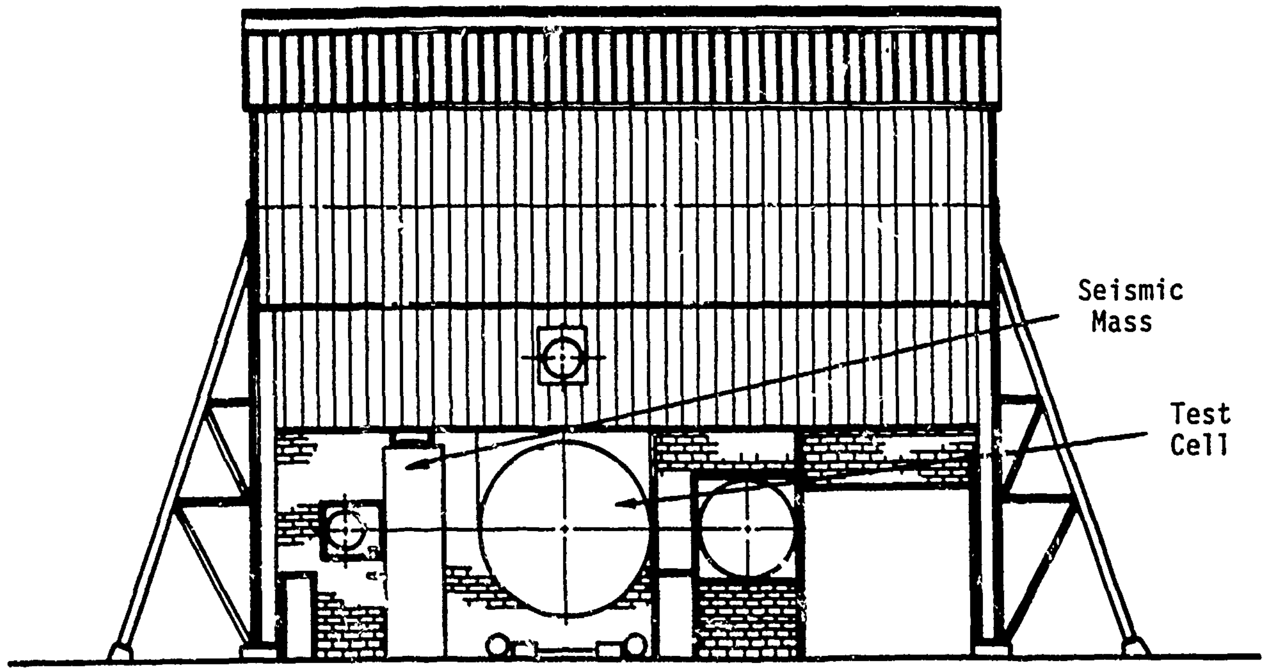


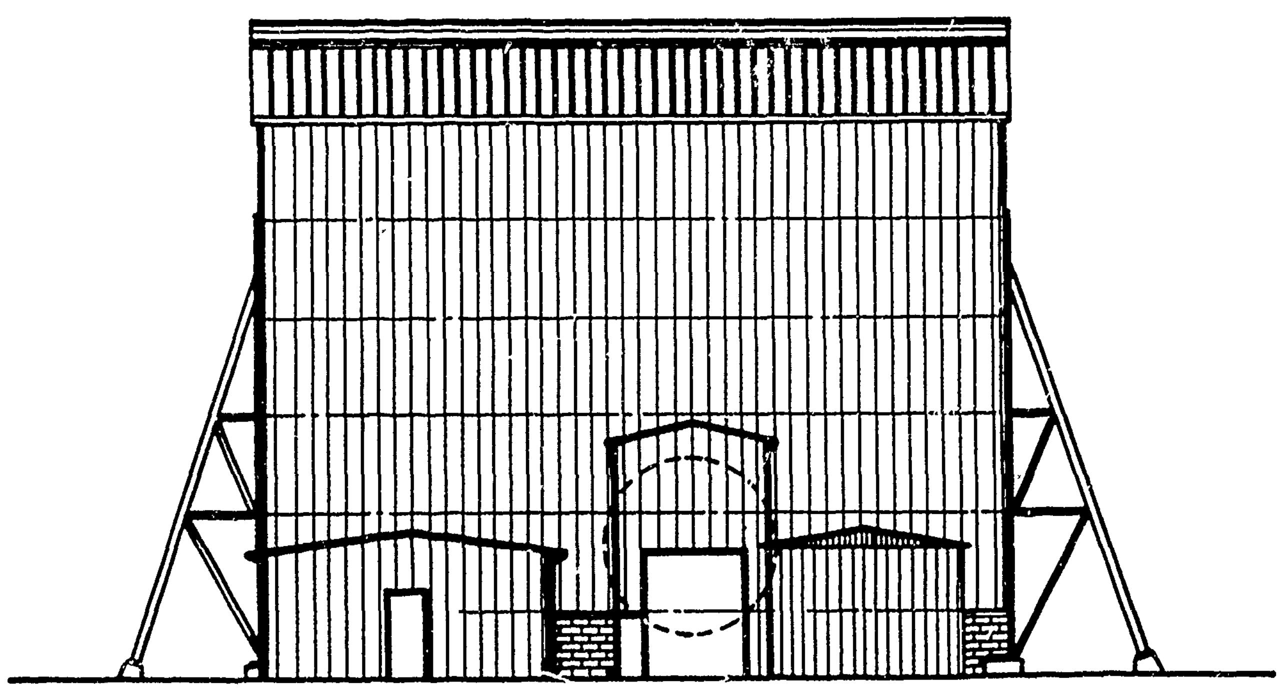
Figure 1. AEDC J-5 Test Facility

relatively debris-free zones around the site. That study was for a proposed large altitude rocket motor test facility (J-6 facility) at AEDC which consists mainly of a large steel test cell and a steel frame, metal siding enclosure building. Hazardous debris densities were determined within various zones around the test cell. The zone boundaries were based on the shape and position of the test cell and on experimental work examining debris distribution from explosions in aircraft shelters (References 2 and 3) and in buildings (Reference 4). The horizontal position of the cylindrical cell made it reasonable to assume cell and motor fragments would be dispersed perpendicular to the axial length of the cell with a limited number of fragments thrown in directions normal to the endcaps. The distribution of building fragments would be concentrated directly out from the walls, with relatively debris-free zones in directions about 45 degrees from the normals to the walls. Although the supporting data were all for reinforced concrete structures, a similar distribution was expected for an explosion inside a predominantly corrugated metal structure.

Elevations of the J-5 enclosure building and an expanded detail of the test cell are shown in Figures 2-4. Since the J-5 test cell and enclosure building are similar to the configuration described in Reference 1, debris were expected to be similarly distributed in zones around the enclosure building. The zones which were established for examining hazardous debris densities are shown in Figure 5. Debris densities were estimated in zones 1, 3, 5 and 7 since the number of debris landing in the other zones was assumed to be minimal. Building debris will be dispersed in directions normal to the walls of the enclosure building. The heaviest concentration of motor casing and test cell fragments was predicted in zone 5 because it extends perpendicular to the horizontal axis of the test cell. Approximately 70% of the total fragments and debris will land in zone 5. Although zone 1 extends in the direction opposite of zone 5, fewer casing and cell fragments will land there since a 5 foot thick seismic mass (see Figure 2) supports the test cell on that side. The seismic mass will stop all but high trajectory fragments. About 20% of the total debris will land in zone 1. The remaining 10% of the debris will be distributed in zones 3 and 7, with slightly more debris landing

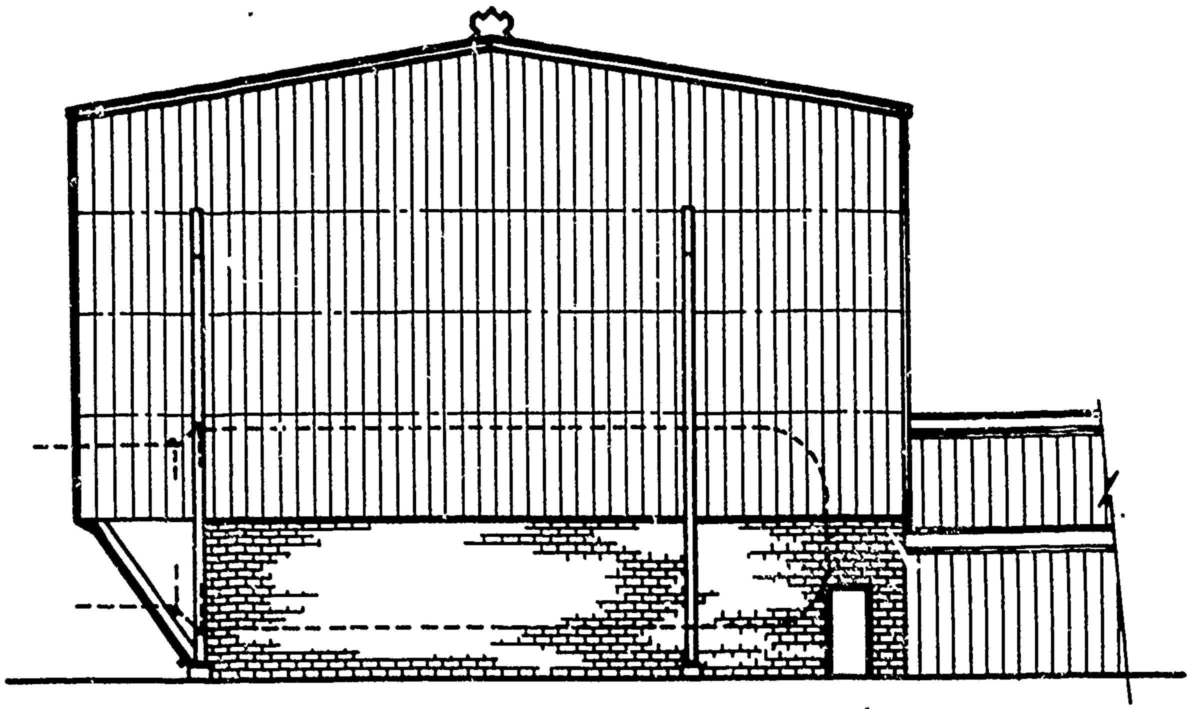


a) North Elevation

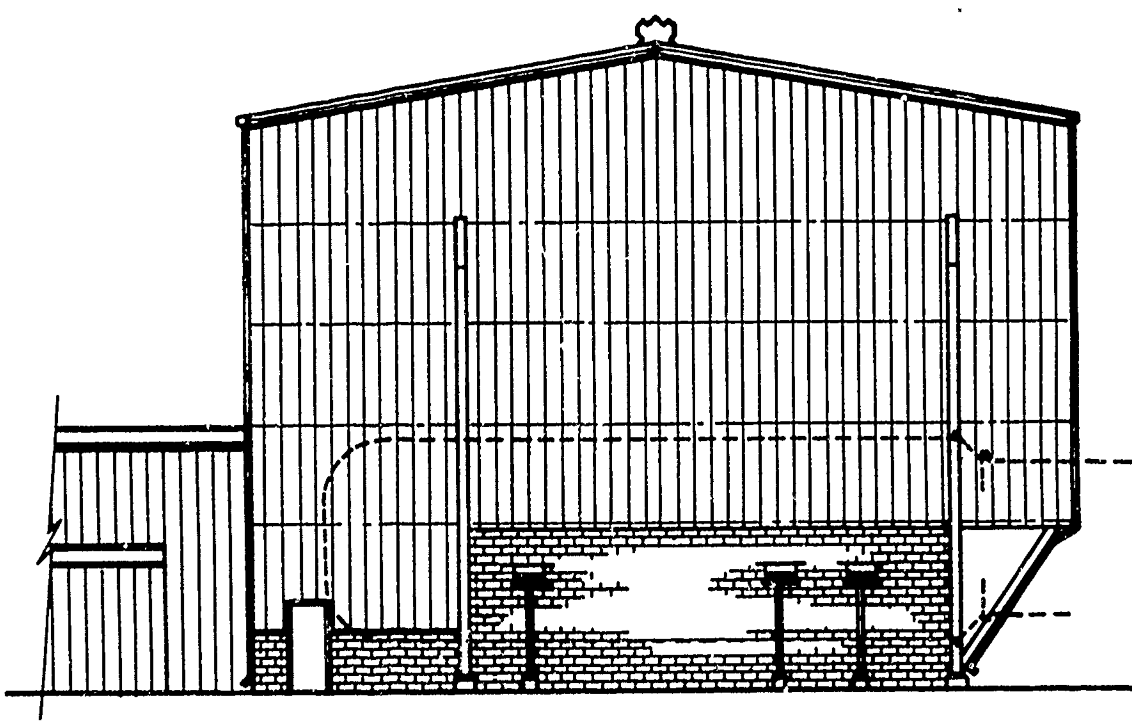


b) South Elevation

Figure 2. J-5 Facility Elevations



a) West Elevation



b) East Elevation

Figure 3. J-5 Facility Elevations

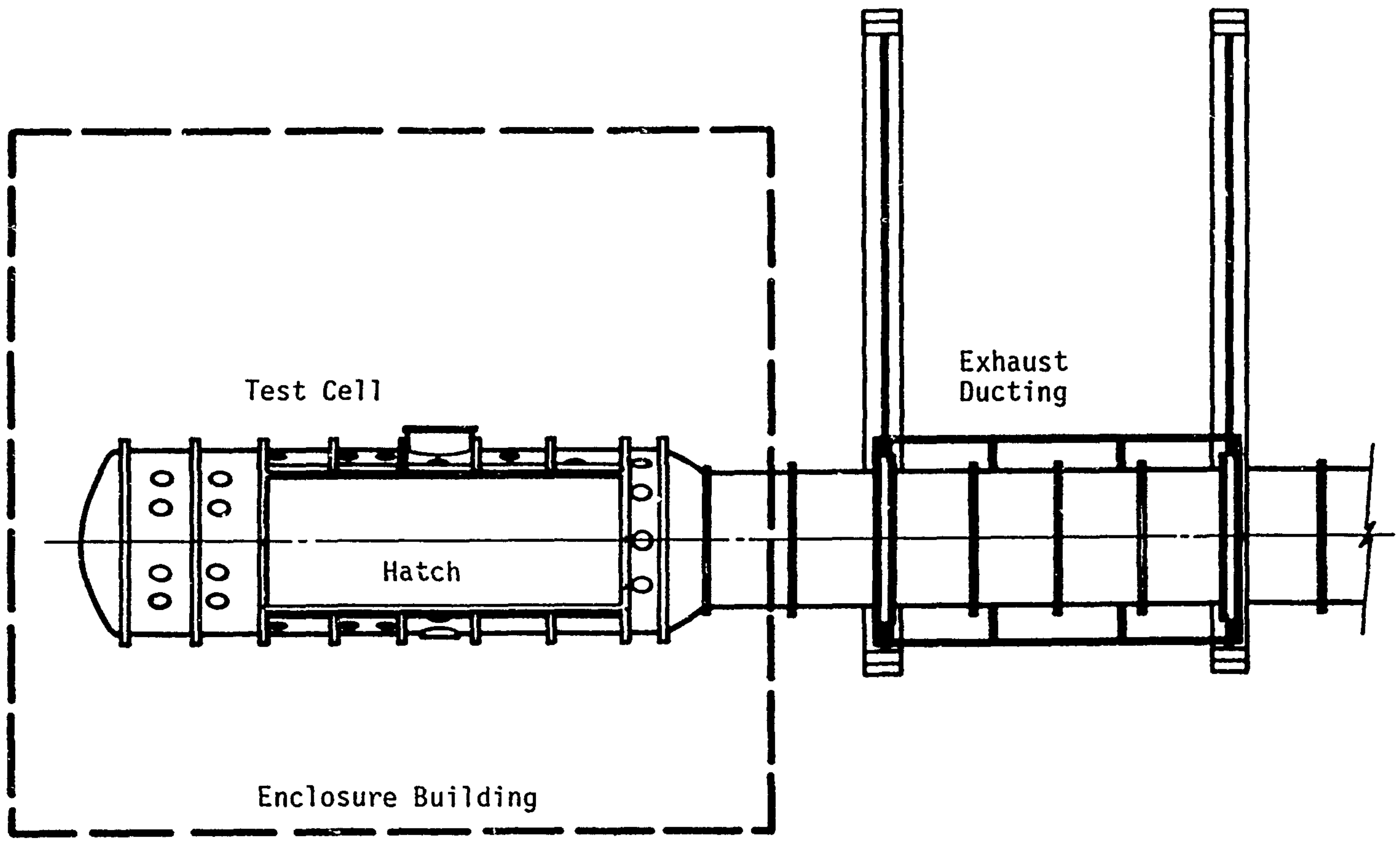


Figure 4. Detail of J-5 Test Cell

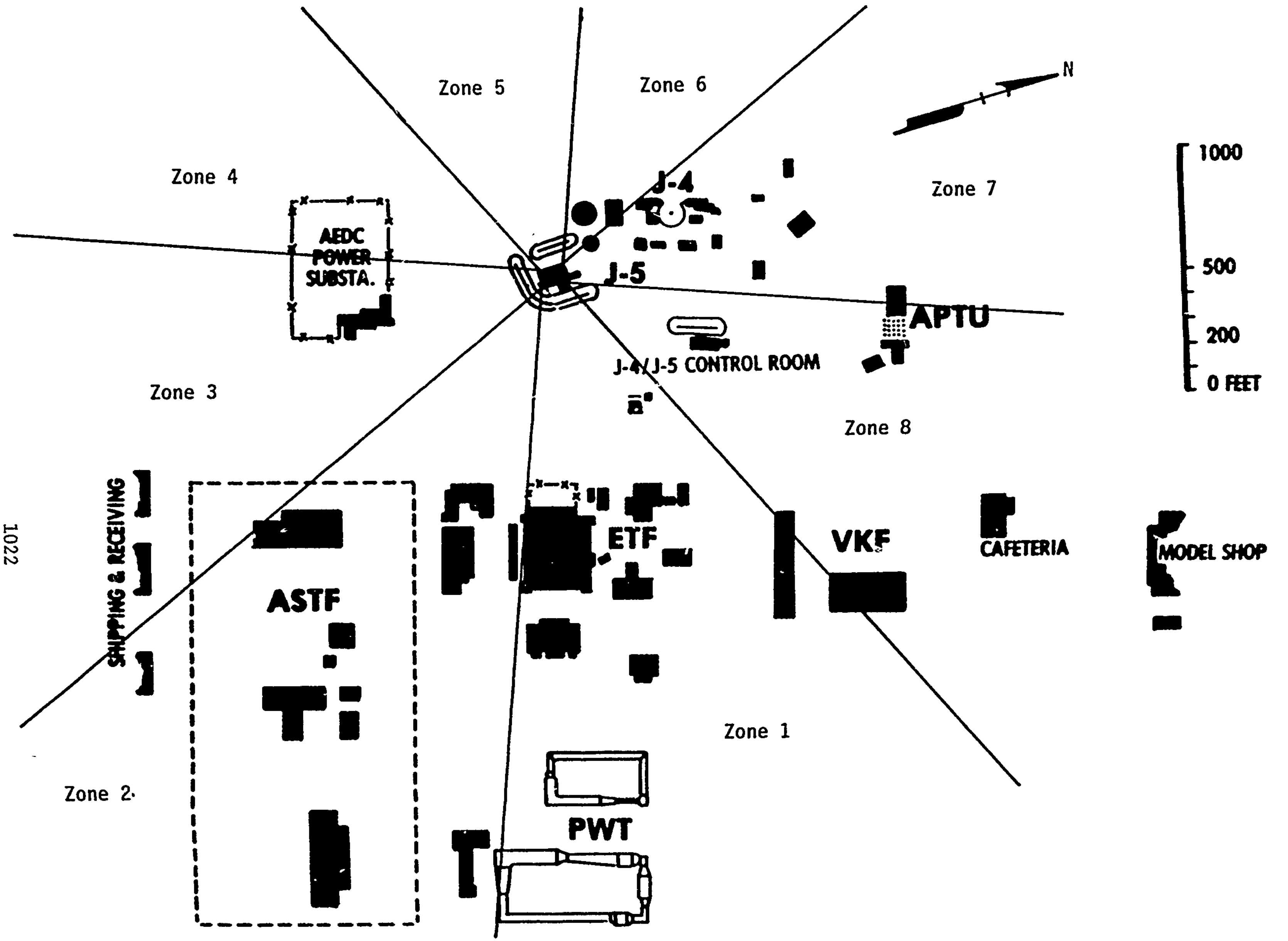


Figure 5. Debris Zones for an Explosion in J-5

in zone 3. The percentage of debris landing in zones 2, 4, 6 and 8 is insignificant. It should be noted that while the percentage of fragments landing in zones 3 and 7 is relatively low, the cell endcaps and hatch covers will most likely impact in these areas. Thus, the damage potential of these large debris is a more important consideration than hazardous debris density in the immediate J-5 area. In summary, the distribution of fragments and building debris was expected to be highly directional with heavy debris concentrations in zones normal to the walls of the enclosure building. Debris paths and concentrations of major debris observed during the mishap investigation lend new support to this theory.

3.0 MISHAP SITE INVESTIGATION

The test being conducted prior to the mishap involved a qualification test of a large rocket motor containing Class/Div. 1.1 propellant. The pressure inside the motor measured about 600 psi just before failure occurred. The peak pressure of 740 psi was measured about 10 seconds into the test. It was estimated that approximately 1100 lb of the original 16,000 lb of propellant remained in the motor when the failure occurred.

An AEDC mishap investigation team was immediately set to the task of determining the cause of the mishap. Their activities included review of manufacturing, shipping and test preparation records, a test procedures review, review and analysis of physical evidence at the site, and interviews of mishap witnesses. In addition to these activities, an SwRI team was allowed to study the site and collect data related to the distribution of debris caused by the mishap. Data collected included the type, size, and origin of debris, along with the impact characteristics and angles of debris throw. Although all identifiable motor casing parts were previously removed from the site, SwRI was provided with a missile map (shown in Figure 6) showing locations of retrieved motor casing fragments (numbered circles) and unburned propellant (circles with an "X" in them). SwRI also used post-mishap photographs (including aerial shots) to help summarize observations on debris and other physical evidence or damage indicators noted during the site investigation.

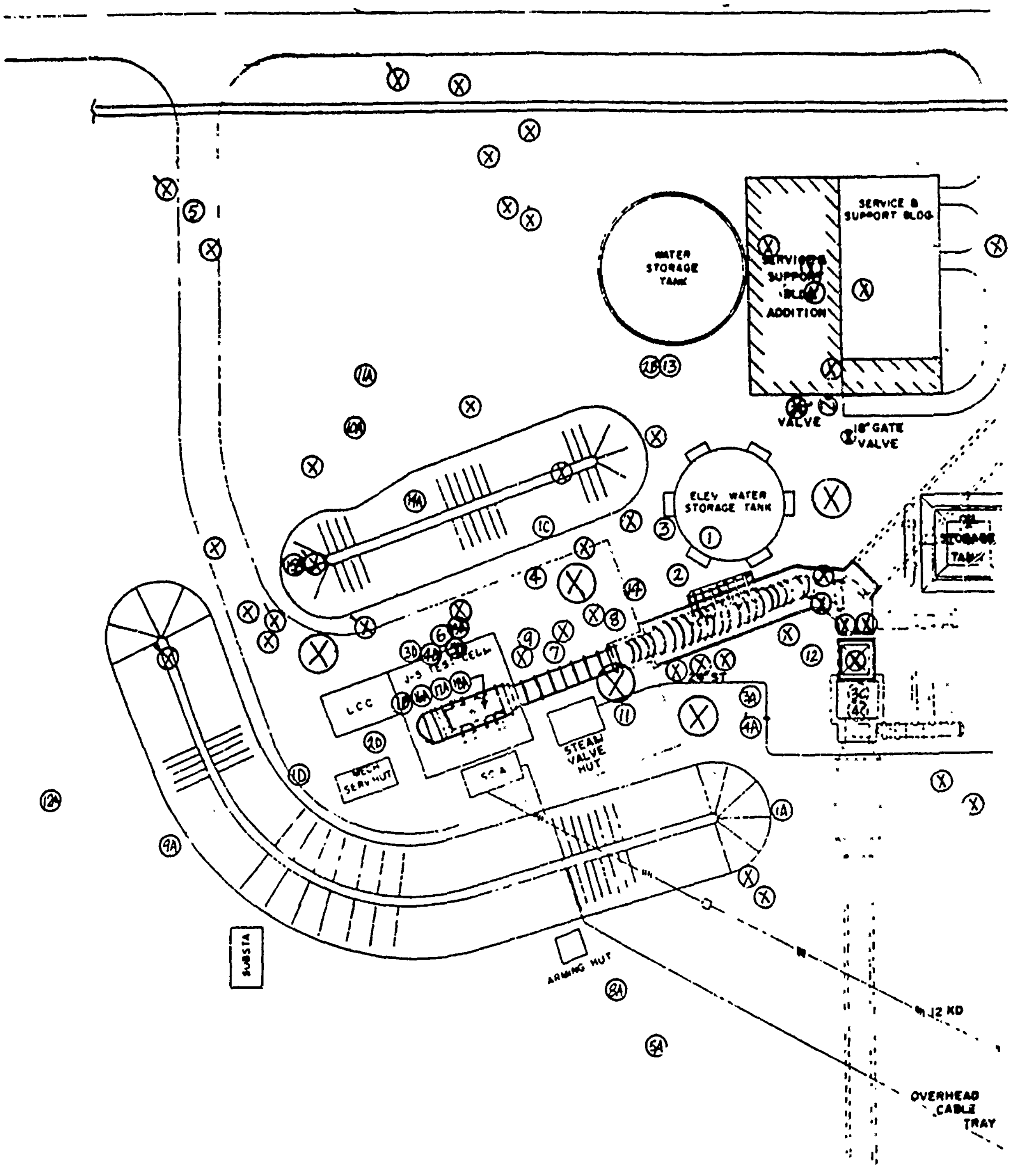


Figure 6. Missile Map Showing Motor Casing Fragments and Unburned Propellant

The hazardous zones predicted for a 20,000 lb TNT equivalent propellant detonation are shown in Figure 7A. The limit distances indicate the threshold of hazardous fragment density, defined as more than one fragment with kinetic energy greater than 58 ft·lb per 600 square feet. Impact locations of a few of the larger cell and building debris from the mishap are shown in Figure 7B. The location of the impacts furthest from the test cell in each zone are indicated on the figure. Note that these are locations of single fragments and do not correspond to the limit distances for hazardous fragment density for the mishap. The hazardous density for the mishap was limited to the bermed J-5 area.

4.0 MISHAP DEBRIS/DAMAGE ANALYSIS

Observations of debris scatter at the mishap site revealed heavy concentrations of debris in directions normal to the test cell enclosure building, establishing new evidence of the zone concept discussed in the J-6 debris study (Reference 1). Figure 8 illustrates these observations. In addition to providing general debris distribution information, the size and position of some of the major debris and the shape and number of motor casing fragments provided physical evidence of the type of explosion which occurred in J-5. Other observed damage indicators were also used to determine the nature of this mishap.

Observations of the test cell breakup pattern and the large size of test cell pieces examined on the initial trip around the site indicated the failure event may not have been a detonation, even though the propellant in the motor being tested was Class/Div. 1.1 (mass detonating) propellant. Also, the small amount of unburned propellant scattered about the site (see Figure 6) and the varied sizes and shapes of motor casing pieces collected earlier did not seem to agree with the initial premise that a detonation had occurred. The difference between a deflagration and a detonation, as it pertains to the J-5 mishap, is that a pressure pulse for a deflagration would be characterized by a smaller peak pressure and a longer duration than the pressure history for a detonation. However, the impulsive load on the test cell and on the structural members of the enclosure building could be just as great. With a

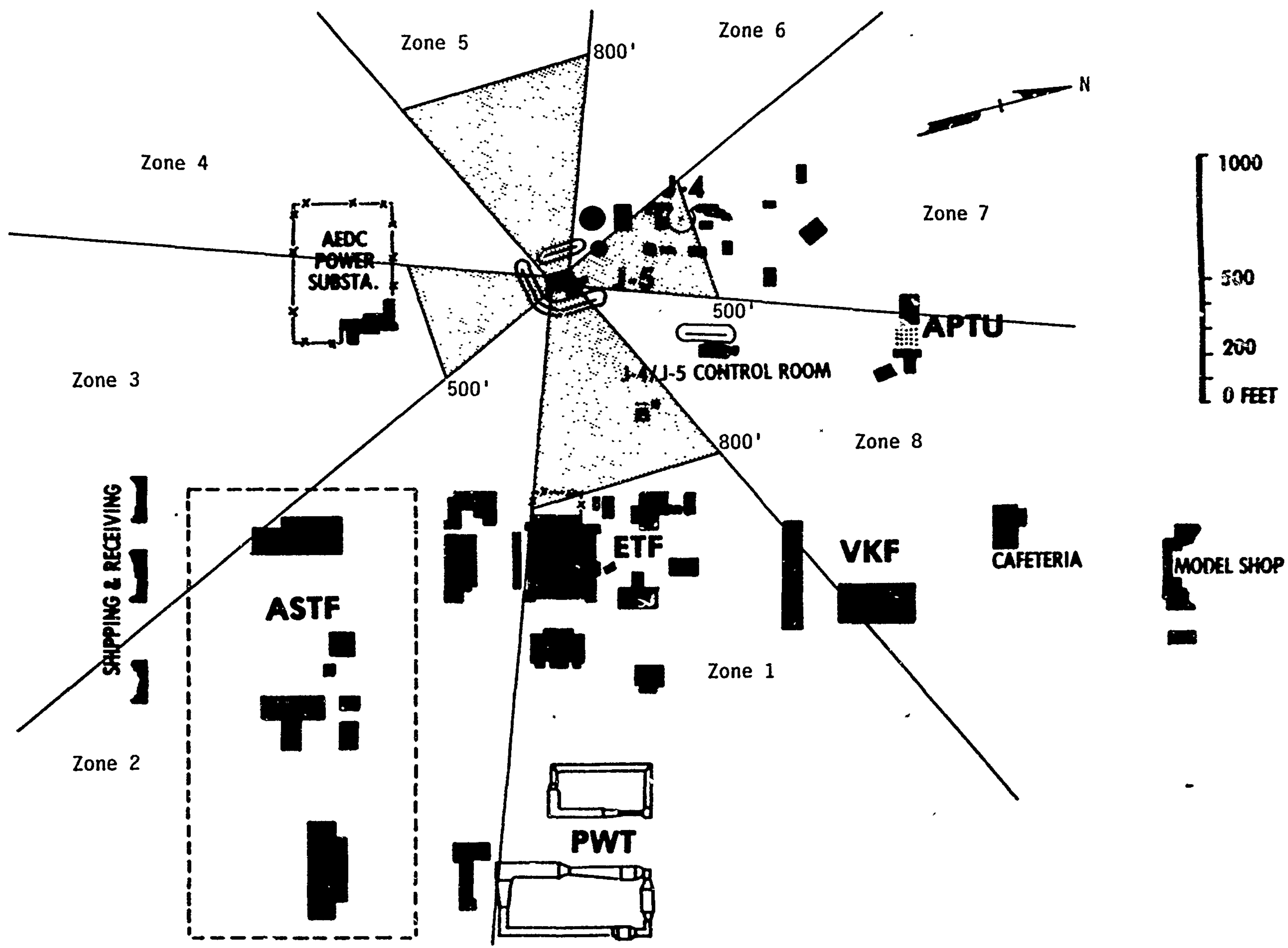


Figure 7A. Hazardous Debris Areas for a 20,000 lb TNT Equivalent Detonation

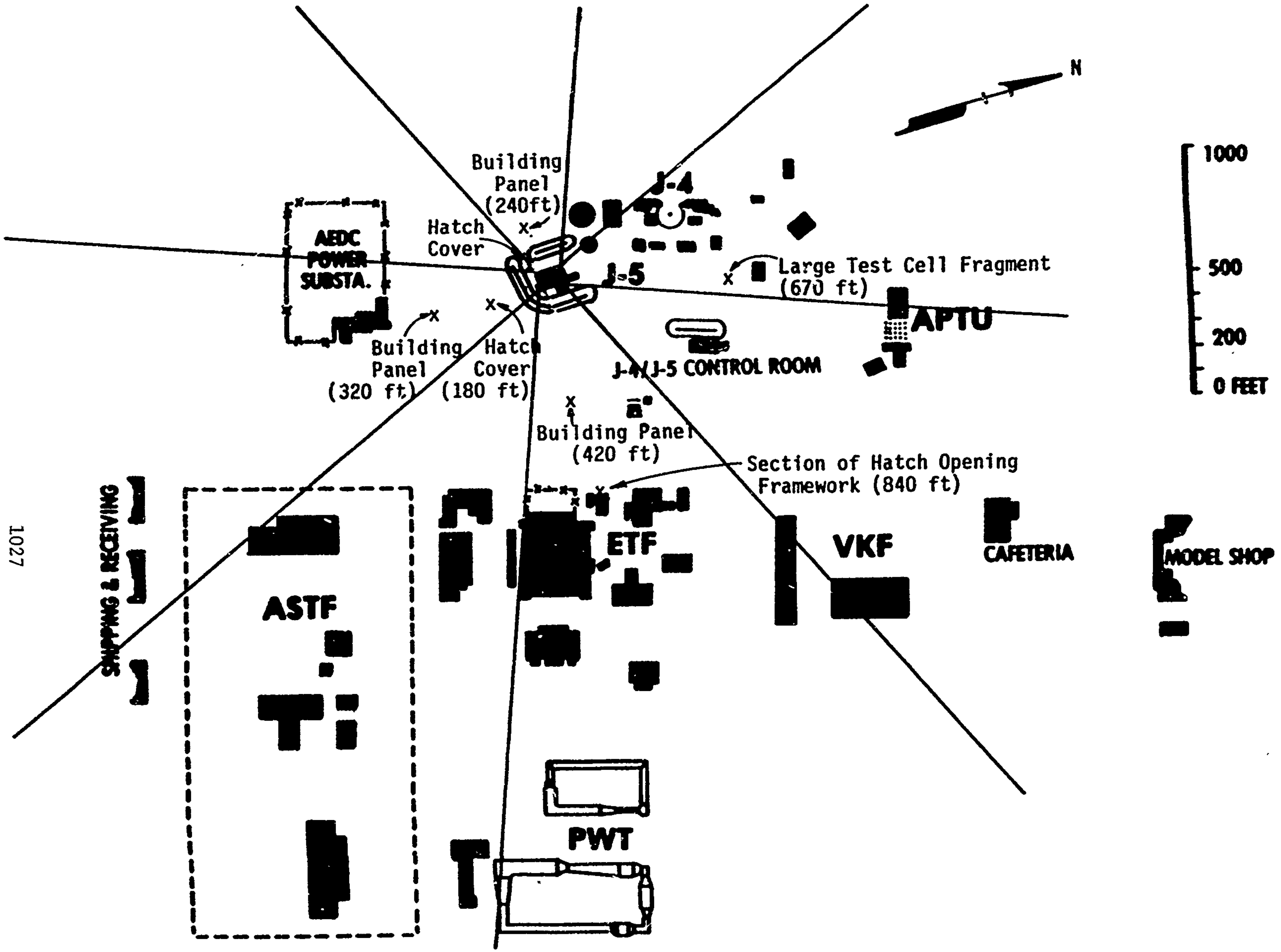


Figure 7B. Major Debris Impact Locations Following J-5 Mishap

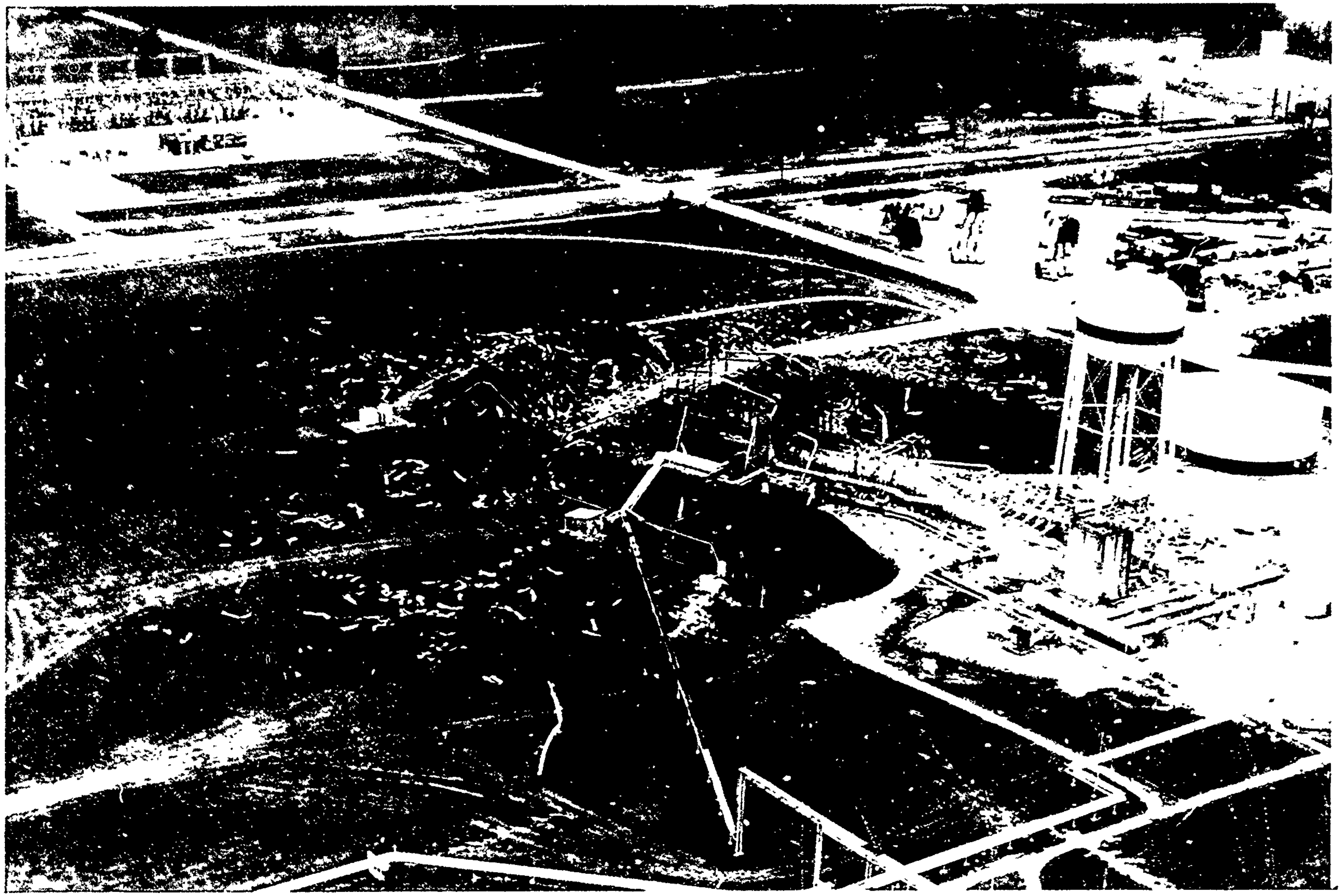


Figure 8. Mishap Debris Distribution

detonating motor, the casing would tend to break into a large number of small fragments. The casing pieces recovered at J-5 were not characteristic of a detonating motor. Further analysis of the other physical evidence noted in the investigation lends credence to a deflagration occurring in the motor.

Calculations were made to define the mishap sequence of events and to confirm the amount of propellant involved in the final event. The approach taken was to assume the reported conditions of the motor just prior to failure were accurate and to calculate debris velocities and ranges and impulse deflections based on a detonation in the motor. Assumed initial conditions at failure were:

- the 1100 lb of propellant in the motor was equivalent to 1375 lb of TNT,
- the motor had a diameter of 92 in. and a length of 125 in.,
- the motor casing weighed approximately 1500 lb,
- the steel test cell had a 16 ft diameter, a length of 50 ft, and a thickness of 0.5 in.

Results of the calculations were then compared with actual observations (measured distances, deflections, etc.) to determine the nature of the mishap.

5.0 CONCLUSIONS - SEQUENCE OF EVENTS

SwRI was doing an analytical distribution study for the J-5 test cell at the time of the mishap. Collecting data on the distribution of debris following the accidental motor failure at J-5 proved to be very useful, as it provided supporting data for the debris zone theory as presented in the J-6 study (Reference 1).

Once at the site, as much data as possible were gathered in the time allotted, including not just debris range and scatter angles, but also any other blast damage indicators or physical evidence of the type of explosion which had taken place in J-5. Based on observations, the test cell appears to have ripped open into a few very large fragments. This fact along with the

small amount of unburned propellant (10 lb) scattered about the site and the characteristics of the recovered casing fragments indicate the mishap involved only a portion of the 1100 lb of propellant present in the motor at the time of failure, and a complete detonation of the remaining propellant did not occur.

Based on the breakup of the motor casing and distribution of casing fragments, SwRI believes something less than a complete detonation occurred near the nozzle which caused a dynamic rupture of the motor casing and subsequent release of unburned propellant into the cell. The further confinement of the propellant within the cell and the increase in propellant burn area caused a greater pressure buildup than the diffuser could handle, resulting in the following events which are relevant to the distribution of debris:

- The cell burst upon failure.
- The pressure buildup caused the two large hatch covers to be projected at high trajectories away from the cell.
- The cell endcaps blew off.
- The cell ripped open on the west side when it struck a stair railing producing several large fragments.
- The east side of the cell was deformed outward by the impact of motor casing pieces and blast and was deformed inward when it struck a bracket on the seismic mass.
- Unburned propellant was expelled from the cell.
- Blast loading inside the enclosure building blew out the metal wall and roof panels.

All analysis of the debris throw and observed damage indicators supports this theory. One of the most important lessons to learn from the J-5 mishap is the recognition of the types of events possible during a test of a motor containing Class/Div. 1.1 propellant and the severity of either a deflagration or a detonation. The observations of debris distribution and blast damage can be applied to the siting of similar test facilities in the future.

REFERENCES

1. Bowles, P. M. and Baker, W. E., "Distribution of Potential Debris and Fragments for an Accidental Explosion in the Proposed Large Altitude Rocket Cell (LARC) at Arnold Engineering Development Center, "AEDC-TR-85-49, November, 1985.

2. Riis, F., "Third Generation Aircraft Shelter, Debris Throw and Air Blast Caused by Accidental Explosions in the Ammunition Cubicle, Report III, Model Tests, Scales 1:20 and 1:100," Fortifikatorisk Notat 149/80, November 1980.

3. Moseley, P. K. and Whitney, M. G., "Prediction of Blast and Debris from an Accidental Explosion Inside a Norwegian Aircraft Shelter," Final Report SwRI Project No. 02-5881, joint study performed with Norwegian Defence Construction Service, NDCS Contract 13600/79/B/FBT 11/AJ/AJ/7209, February 1981.

4. Bergmann, S.G.A., "Swedish Protective Structures for Manufacturing Units Constituting Explosion Hazard in the Range 1 - 2,000 Pounds of TNT," <u>Annals of the New York Academy of Sciences</u>, Vol. 152, Art. 1, October 1968.